# Electrical Characterizations of Polypyrrole Thin Film Deposited on Glass Surfaces by Using the LCR Meter

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***Abstract*—The electrical characterization of Polypyrrole (PPy) thin films is investigated as a function of various thin film thickness. Ten sets of uniform PPy thin films with different layers were prepared by using the spin coating method applied on glass substrates treated with oxygen plasma. The electrical resistance, inductance, conductance of the films was observed as a function of film thickness at room temperature. These parameters have been measured by using the LCR meter. The behavior of the PPy thin film's resistance was then interpreted in terms of resistivity and conductivity. The results showed that as the thickness of the thin film increase, the resistivity decrease thus increasing its conductivity.**

***Index Terms*—Capacitance; Conductivity; Inductance; LCR Meter; Polypyrrole (Ppy) Thin Film; Resistance; Resistivity.**

## I. INTRODUCTION

Polypyrrole (PPy) are among the most studied polymers reflected by the amount of publication surrounding its properties and applications especially in the biosensing area [1]. PPy is reported to be useful as an electrical conductor [2]. PPy conducting polymers offers a wide range of medical applications due to its interesting and tuneable properties, good thermal and environmental stability, facile synthesis, high storage ability and higher conductivity than many other conducting polymers [3-5]. PPy also makes a very promising smart material as they possess excellent qualities and stimulus-responsive properties [1]. Most importantly, PPy has good biocompatibility and chemical stability [1]. However, it was reported that many applications of PPy have not yet been realized because the conductivity of the conducting polymer is not sufficient for applications that require high current capacity such as microcircuits and conducting pastes.

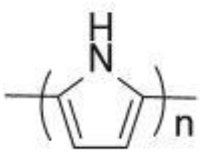

Figure 1: Main chain of Polypyrrole (PPy) [6]

Figure 1 shows the main chain structures of conjugated polymers, PPy. PPy consist of a conjugated structure [1] with alternating single and double bonds bond holding the atoms of the polymer together, creating an extended π-bond network. Along the backbone, the sigma bond holds each atom together by concentrating electrons directly between the π-bond in each double bond, strengthen the connection between them by attracting electrons above and below the planes of the molecules forming delocalized orbitals. The movement of electrons within the π-orbitals is the source of conductivity for this type of polymers.

This present work focuses on the electrical characterization of the PPy thin film with the function of PPy thickness. This experiment is a preliminary study that will be a starting point towards the biomedical field. PPy is a conducting polymer being a promising candidate for biosensing technologies such as temperature sensors and flexible electronics. Also, the recent research field has shown tendencies into the revolution of the PPy material which focused on miniaturization of electrochemical components in which they prefer thin film rather than the polymer in bulk [7].

## II. SPECIMEN PREPARATION AND EXPERIMENTAL SETUP

### *A. Chemicals*

Polypyrrole doped in organic acids, 5 wt% dispersion in water purchased from Sigma Aldrich (482552-100 ml), Ethanol (95% of purity, molecular weight: 46.07g/mol) and Deionized (DI) water.

### *B. Surface Treatment by Oxygen Plasma*

The glass substrates (long: 25.4 mm x width: 25.4 mm x thickness: 1 mm) were first consecutively rinsed with Ethanol and DI water respectively to remove any organic contaminant. Then the glass substrates were immersed in an Ethanol solution for approximately five minutes to make the glass substrate hydrophilic since PPy immersed in water is hygroscopic. After the immersion, the glass substrates were dried by an air gun. After the drying process, the cleaned glass substrate was then exposed to the oxygen plasma for approximately 6 minutes to promote more oxygen group creating temporary hydrophilic charges on the glass and increase the spreading.

### *C. Preparation of the PPy thin Film*

The PPy thin films were deposited by using the spin coating method on pre-cleaned glass substrates. The spin coating process was performed at room temperature by using the spin coater. 1 ml of PPy liquid was deposited on glass substrates, which were spun for 5s at 500 rpm (stage 1) and 20s at 1899 rpm (stage 2) with the acceleration of 1000 rpm/s respectively. The obtained film was in black color and was dried on a hotplate at 70 °C for 2 minutes. Ten specimens of the PPy thin film were obtained. The subsequent layer of PPy was deposited right after the first layer of PPy were completely dried. The same process was applied to all deposited layers.

## III. RESULTS AND DISCUSSION

### *A. . Thin Film Thickness Study*

Table 1
Thickness Measurements of the PPySpecimen's Film Deposited with Different PPy Layers

| PPy Layers | PPy Thickness (µm) |
|---|---|
| 1 layer | 0.0823 |
| 2 layers | 0.0886 |
| 3 layers | 0.1159 |
| 4 layers | 0.1324 |
| 5 layers | 0.1324 |
| 6 layers | 0.1339 |
| 7 layers | 0.1574 |
| 8 layers | 0.1849 |
| 9 layers | 0.2107 |
| 10 layers | 0.2586 |

The identified thickness for each deposition layers from layer 1 to layer 10 is as shown in Table 1.The measurement of the thickness of each layer of PPy was determined by using a profiler meter, a High Power Microscope (HPM) from DextarTAR. The measurement for the thickness of the PPy specimen was taken from 3 points and the thickness mean value was calculated. Generally, the PPy thickness increases with the increases of PPy layers.

### *B. Electrical Characterization Study*

The resistance, inductance and capacitance specimens of the PPy thin films spin-coated on the glass substrates were determined using GW INSTEK LCR meter (LCR-8101G) at room temperature. Average values are then calculated based on 10 sets of readings for each specimen. The probe separations for each measurement taken is 1 cm. Table 2 shows the average values of resistance, inductance and conductance in the function of PPy thickness.

Table 2
TheAverage Values of Resistance, Inductance and Capacitance in the Function ofPPy Thickness.

| PPy Thickness (µm) Resistance (kΩ) | Inductance (mH) | Capacitance (pF) | PPy Thickness (µm) Resistance (kΩ) |
|---|---|---|---|
| 0.0823 | 69.199 | 103.430 | 33.975 |
| 0.0886 | 65.115 | 110.762 | 37.875 |
| 0.1159 | 63.206 | 112.097 | 38.436 |
| 0.1324 | 61.248 | 115.525 | 39.133 |
| 0.1324 | 59.115 | 125.498 | 40.751 |
| 0.1339 | 57.524 | 129.443 | 41.728 |
| 0.1574 | 56.277 | 131.486 | 42.549 |
| 0.1849 | 53.314 | 137.501 | 43.098 |
| 0.2107 | 50.824 | 148.290 | 44.550 |
| 0.2586 | 48.758 | 154.585 | 47.906 |

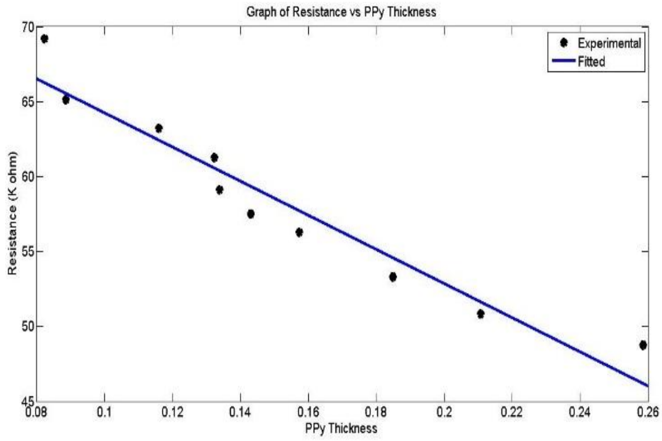


Figure 2: Resistance graph

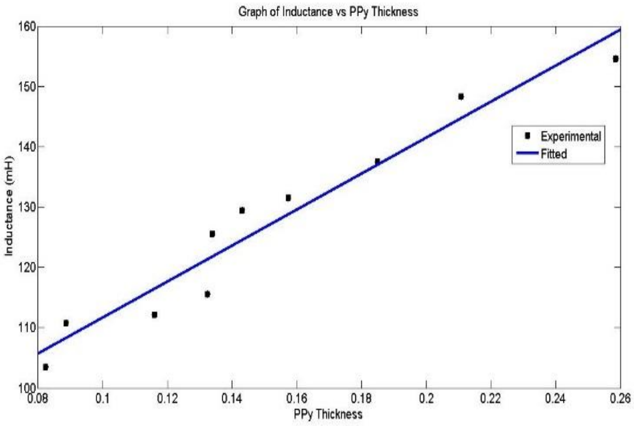


Figure 3: Inductance graph

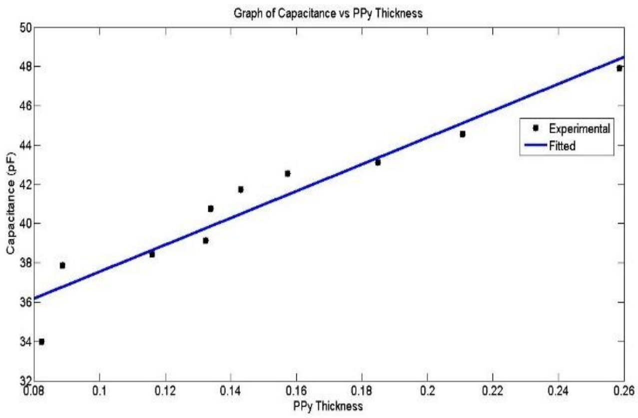


Figure 4: Capacitance graph

The graph of the average electrical resistance, inductance and capacitance at room temperature with films thickness are shown in Figure 1, Figure 2 and Figure 3.It shows that in Figure 1, the increases of the thickness of PPy thin films, the resistance decreases suggesting an increase of power output. In Figure 2, it was observed that inductance increase with the PPy thickness. The inductance values showed that the PPy specimen has the property to cause an increase in electromotive force to be generated in a function of increasing thickness. In Figure 3, capacitance shows an almost constant behavior as the thickness increases. The increasing measurement of capacitance proved that the PPy material could enhance the material's energy storage with increasing thickness.

Table 3
The Average Values of Resistivity and Conductivity in the function of PPy Thickness.

| PPy Thickness (μm) Resistance (kΩ) | Inductance (mH) | Capacitance (pF) |
|---|---|---|
| 0.0823 | 44.1427 | 0.0227 |
| 0.0886 | 38.5839 | 0.0259 |
| 0.1159 | 28.6308 | 0.0349 |
| 0.1324 | 24.2864 | 0.0412 |
| 0.1339 | 22.0578 | 0.0453 |
| 0.1431 | 20.0992 | 0.0497 |
| 0.1574 | 17.877 | 0.0559 |
| 0.1849 | 16.5795 | 0.0603 |
| 0.2107 | 12.6638 | 0.0789 |
| 0.2586 | 9.8986 | 0.101 |

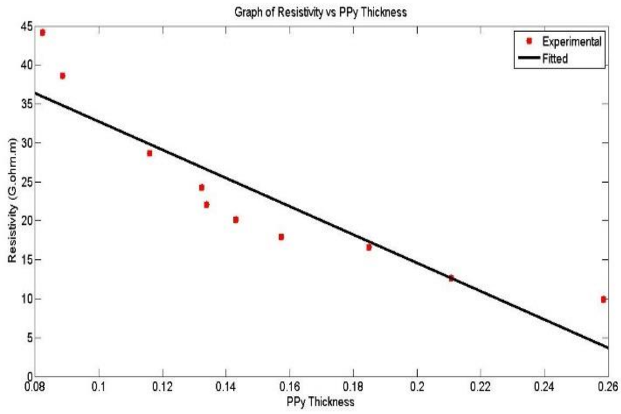


Figure 5: Resistivity graph

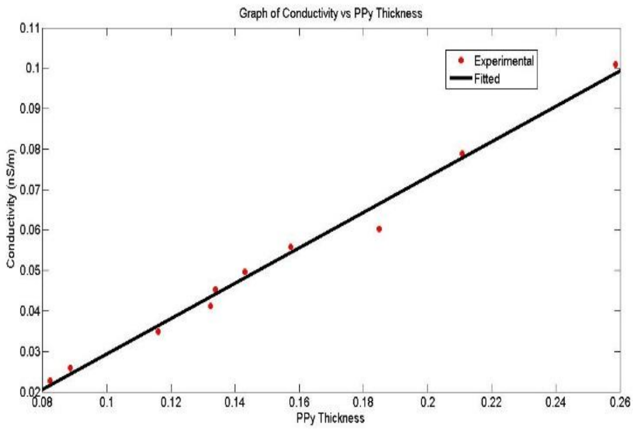


Figure 6: Conductivity graph

Table 3 shows the results of average electrical resistivity and average electrical conductivity which were determined for PPy thin films of different thicknesses. Figure 3 shows the plot of resistivity as a function of film thickness. The resistivity decreases when films thickness increases. It was also observed that as the PPy thin film increases, the conductivity increases thus suggesting that the deposited thin films conductive behavior have been confirmed since current is able to flow across the specimen such as shown in Figure 4. The resistivity and conductivity values were calculated by using the expression in (1) and (2) respectively, where R is the resistance value for each specimen, A is the cross-sectional area and $l$ is the thickness of the PPy on the glass substrate.

$$\text{Resistivity, } \rho = R \times (A/l) \tag{1}$$

$$\text{Conductivity, } \sigma = 1/\rho \tag{2}$$

## IV. Conclusion

The electrical properties of the PPy thin film deposited on glass substrates with the thickness of 0.0823 μm to 0.2586 μm have been studied. A methodology to deposit and characterize PPy conductive polymer thin films as a function of thickness is discussed. From that results, it shows that PPydeposited on glass substrate treated with plasma preen and deposited on a glass substrate showed electrical activities, given a value of 1V of DC input and 60 kHz of LCR test frequency. This experiment achieves to investigate the electrical characteristics of PPy in terms of resistance, capacitance and inductance. Furthermore, this experiment succeeds to show the relationship between the thicknesses of the PPy with its conductivity value. The present study will be extended in future to investigate the PPy with a suitable doping agent and solvent in order to improve the electrical properties and conductivity. Moreover, the conductivity will also be measured with the effect of different surface roughness. In addition, the conductivity will be obtained from the resistance measurement with the function of temperature to confirm the thermally activated behavior of PPy conductivity.

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